

Simulation and analysis of distributed PV generation in a LV network using MATLAB-Simulink

Jose R. Rodriguez⁽¹⁾, Felipe Ruiz⁽²⁾, Domingo Biel^(1,3), Francesc Guinjoan⁽³⁾

(1) IOC-UPC-Spain, (2) DE-UTEM-Chile, (3) DEE-UPC-Spain

Email: raul.rodriuez-villarreal@upc.edu, fruizallende@utem.cl, biel@eel.upc.edu, guinjoan@eel.upc.edu

Abstract—Power quality of electric networks with high penetration of photovoltaic systems has been analyzed in different publications. It has been noted that inverters may increase their harmonic emissions when connected to weak networks, this harmonics may affect other equipments connected to the network and decreasing their performance. This document shows the effects of connecting multiple photovoltaic generators in a network through simulations using MATLAB-Simulink SimPowerSystems.

I. INTRODUCTION

The growing of distributed generation with photovoltaic (PV) systems may diminish the power quality of the distribution networks. Higher levels of harmonic distortion have been detected in residential networks with high penetration of PV systems [1], this level of distortion may affect the performance of some equipment connected to the network, including the PV systems themselves. Among other perturbations, harmonics may excite resonances and produce the distortion of the network's voltage due to the existing impedances.

The problem is complex since loads consumption and PV generation are variable and depend on many different parameters: consumption, weather conditions, the point of connection (POC) of the PV inverters, leading to new challenges to overcome in the design of controllers for grid connected inverters.

A simulation environment has to be developed in order to analyze this phenomenon to farther evaluate the capabilities of new controllers; these goal constitutes the main purpose of this work, in which we present a Matlab simulation environment that allows us to study the phenomenon.

The paper is organized as follows: in the second section we present the microgrid network to simulate, where as in the third section the electrical models used in the simulation environment are presented. The simulation results are shown in the fourth section and finally the fifth section draws some conclusions of this work.

II. MICROGRID ENERGETIC SCENARIO: CASE OF STUDY

The microgrid network model considered in this document is shown in Fig. 1. It includes a MV/LV distribution transformer, 5 PV generators connected at different locations, a set of loads and cables. Each PV generator is connected to the grid through an inverter of 5kW nominal power; each load represents the power consumed by a set of lumped houses and the cables are characterized by their length and crossover section.

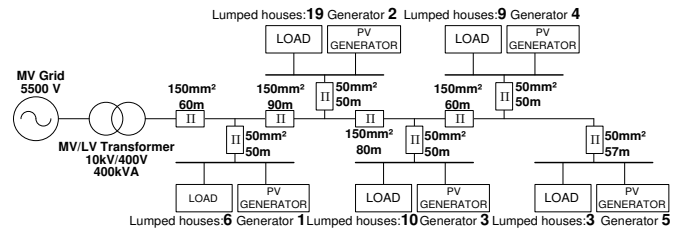


Fig. 1. Residential Network Model

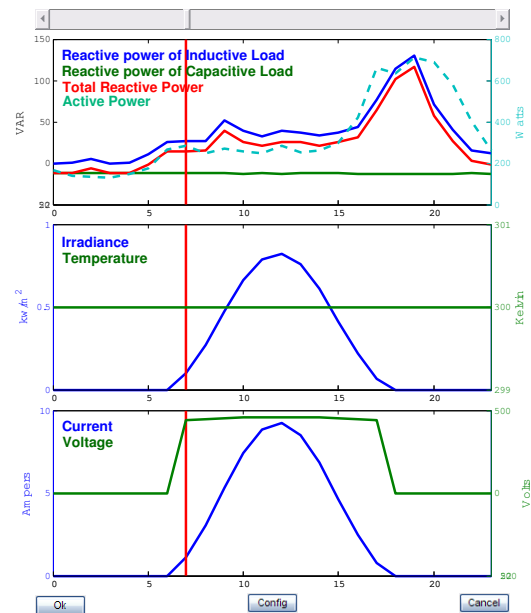


Fig. 2. Profiles of a) household consumption, b) Irradiance and temperature, c) Voltage and current of the PV panel.

The PV generation and consumption profiles considered are shown in Fig. 2, where the upper graph shows the active and reactive power consumption of a single house along the day, in the middle graph are the irradiance and temperature of the PV panels (assumed at 27°C) and finally the lower graph shows the current and voltage of each PV panel when it operates at its maximum power point (MPP).

III. ELECTRICAL MODELS

The following electrical models have been used in the network simulation.

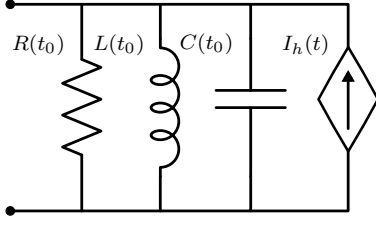


Fig. 3. Load model.

TABLE I
ELECTRIC PROPERTIES OF CABLES

Transversal section mm^2	Resistance Ω/km	Inductance H/km	Capacitance F/km
150	0.616	0.17e-3	197e-9
50	0.494	0.23e-3	147e-9

A. Lumped houses loads

In [2], both active and reactive power consumption as well as the harmonics content of the loads are modelled as a single current source from the measurements taken in different houses in order to obtain a harmonic pattern. However, in this work we model the power consumption as a parallel RLC circuit, see Fig. 3, in order to show the resonances in the grid. Additionally, in parallel to the RLC circuit a current source is connected to reproduce the harmonic contents. The amplitude of such harmonics is computed based on the polynomials described in [2].

In Fig. 2a the active and reactive power profiles along the day used in our simulations are presented. The profile of the active power consumption for a single house was obtained according to [3], whereas the reactive profile was obtained from [4].

B. Distribution cables

The cables are modelled by sections of a Π circuit, as shown in Fig. 4. According to Matlab SimPowerSystems toolbox facilities, the user computes the amount of sections depending on both the cables length and the maximum frequency to analyze. For the case under study which analyzes the behaviour up to the 500 harmonic (i.e. 25kHz) a single Π circuit properly models a cable length of 90m. The length and crossover section of each cable is shown in Fig. 1, whereas the corresponding parameter values of the electrical model are reported in Table I.

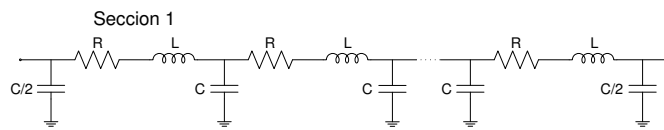


Fig. 4. Cable model.

TABLE II
TRANSFORMER MODEL

R_1	0.5Ω	R_2	0.5Ω
L_1	$63.7mH$	L_2	$63.7mH$
R_m	$125\text{ k}\Omega$	L_m	$398H$

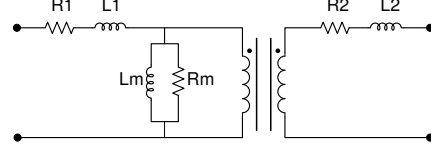


Fig. 5. Transformer model from the SimPowerSystems Matlab library.

C. MV/LV Transformer

The transformer model is obtained from the Matlab SimPowerSystems toolbox and is depicted in Fig. 5. For the case under study, the nominal power of the transformer is 400kVA and the nominal voltage is 10kV/400V. Table II shows the parameter values of the model.

D. Medium voltage network

Since the goal of this work is to study the resonant effects in a strong grid as more PV inverters are connected to it, the MV network is modelled as an ideal voltage source of 5500Vrms and 50Hz.

E. PV inverter

This work assumes an averaged behaviour of the inverter which is modelled as a controlled voltage source linked to the POC through an LC filter, as shown in Fig. 6. The controlled source delivers a voltage given by $d \cdot V_{max}$, where V_{max} corresponds to the PV generator output voltage at the MPP and d to the duty cycle driving the inverter. The control signal d comes from a PI-based current control loop which compares the current at the POC with a sinusoidal current reference $\alpha \cdot V_{PLL}$ which is hold in phase with the POC grid voltage through a PLL. The value of α carries the DC power of the PV generator, P_{max} , and is given by $\alpha = P_{max}/V_{RMS}^2$, being V_{RMS} the RMS voltage value at the POC. In addition, the control signal d is clamped to the working range $[-1,1]$ to take into account the eventual saturation of the control.

F. PV panels

The current I_{pv} given by each panel is modelled by equation (1).

$$I_{pv} = N_p(I_L - I_0(e^{\frac{V_{pv}}{N_s V_t}} - 1)) \quad (1)$$

Where I_L and I_0 are the photogeneration and the saturation currents respectively of a single cell, V_{pv} is the panel voltage and V_t the thermal one, being N_p and N_s the number of cells connected in parallel and series respectively. In the simulation the values of I_L , I_0 and V_t for a single cell are computed according to [5].

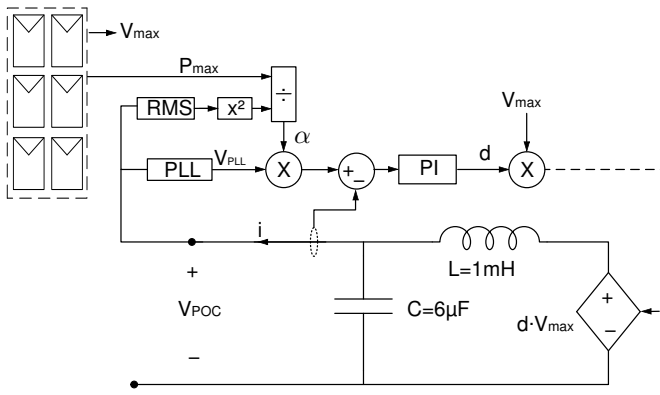


Fig. 6. Power converter system.

The panel voltage value at MPP, V_{max} , is obtained from (1) by solving $dP_{pv}/dV_{pv} = 0$ for V_{pv} , using Matlab facilities.

IV. SIMULATION PROCEDURE

The flow chart of the simulation execution is shown in Fig. 7. The user previously selects an hour of the day to perform the simulation. In accordance, the values of the load active and reactive power consumption and the PV generation parameters given by P_{max} and V_{max} are previously computed from the curves of Fig. 2a, 2b and 2c respectively at the selected hours and constitute the initial values required by the simulation. The simulation starts with these initial values and with the parameter values of the electrical models involved in the microgrid and delivers all the electrical variables.

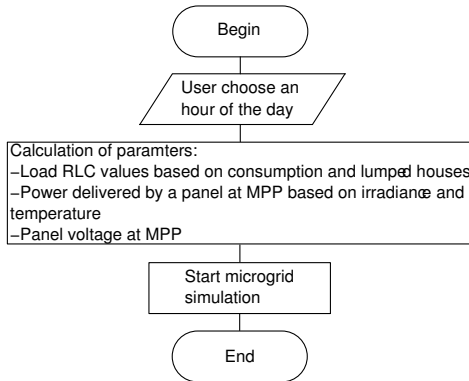


Fig. 7. Flow chart of the simulation process.

V. SIMULATION RESULTS

This section presents the results of 4 simulations considering different scenarios of load consumption and PV generation. The goal is to show the POC voltage distortion dependence with the consumption and generation levels, as well as with the number of inverters connected to the microgrid.

To do so, a first set of 3 simulations assumes 5 inverters connected to the microgrid according to the location of Fig. 1 and operating under the same irradiance at the same temperature fixed at $T = 27^\circ C$. Referring to Fig. 2, the first

simulation takes place at 7:00 when both the consumption and the irradiance levels are low, the second one takes place at 12:00 when the irradiance is maximum, and finally, the last one is at 17:00 when the consumption is high and the irradiance is low.

The simulation results, carried out for an overall simulation time of 0.2s, are presented in Figs. 8, 9 and 10 and show both the voltage at the LV side of the transformer and the voltage of each inverter at its POC (right plots). The corresponding harmonic spectrum is shown in the left plots, where the amplitude of the harmonics is normalized to the amplitude of the fundamental frequency.

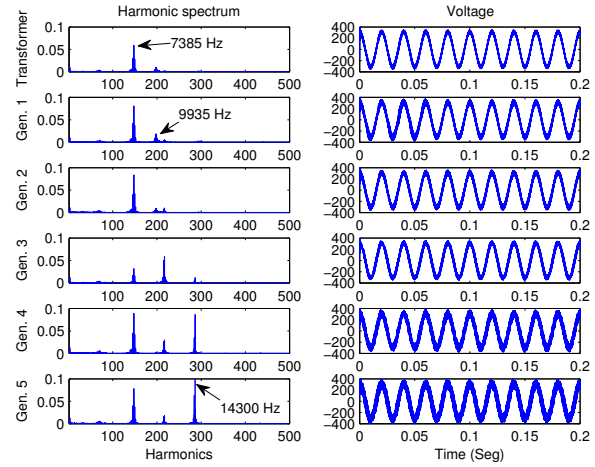


Fig. 8. Simulation at 7:00 with 5 inverters connected to the microgrid.

The simulation of Fig. 8 is at 7:00, each PV panel delivers 494W of power and a voltage of 441V. The total consumption of each house is 15VAR and 286W.

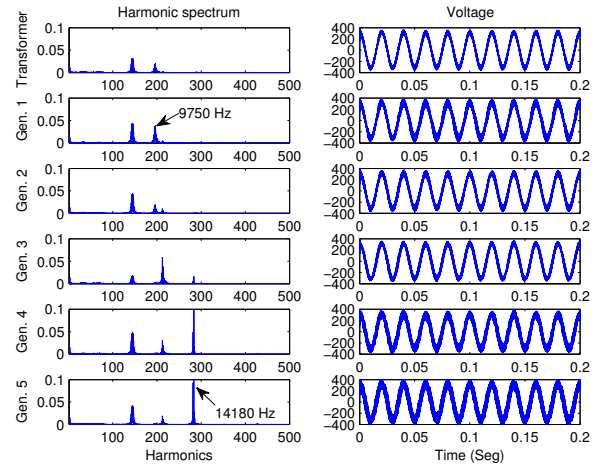


Fig. 9. Simulation at 12:00 with 5 inverters connected to the microgrid.

Fig. 9 shows the simulation results at 12:00 when each PV panel delivers 4216W of power and a voltage of 457V. The

total consumption of each house is 26VAR and 286W. Notice that the harmonics resonate at different frequencies from the previous simulation of Fig. 8.

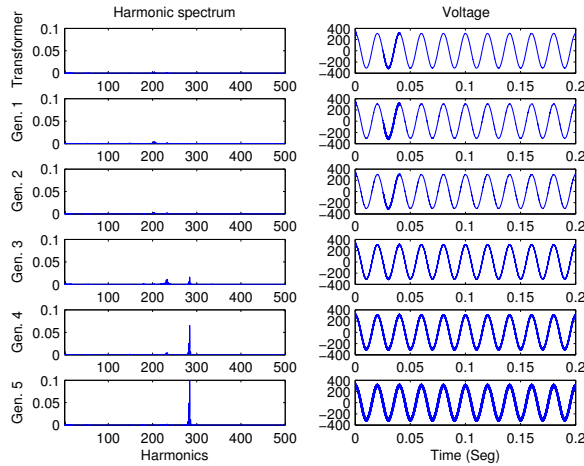


Fig. 10. Simulation at 17:00 with 5 inverters connected to the microgrid.

Fig. 10 presents the simulation results at 17:00 when each PV panel delivers a power of 327W and a voltage of 437V. The total consumption of each house is 64VAR and 663W. As it can be seen the harmonic content is lower than in previous simulations.

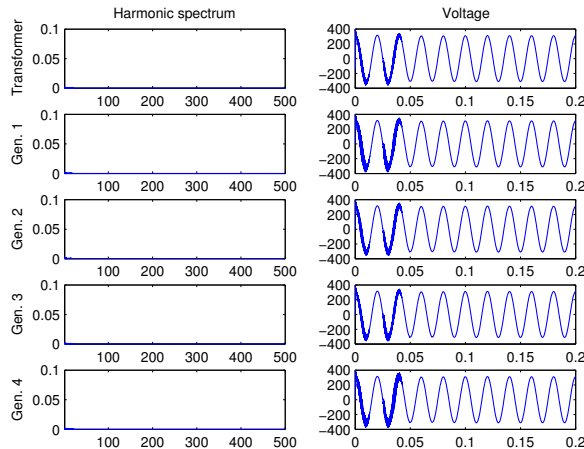


Fig. 11. Simulation at 12:00 with 4 inverters connected to the grid.

Finally, in order to evaluate the influence of the number of connected inverters, the last simulation also takes place at 12:00 as in Fig. 9 when a PV panel delivers a power of 4216W and a voltage of 457V but considers 4 inverters instead of 5 (the 5th inverter at the end of the line is removed). The total consumption of a house is 26VAR and 286W. Notice the resonances at the POC of each inverter are not present.

VI. CONCLUSIONS

This work has presented a simulation environment in Matlab-Simulink for the analysis of PV generators connected to a micro-grid. The parameter values of the developed models vary as generation and consumption power do along the day in order to simulate different scenarios. The simulations results obtained for the four different scenarios lead us to the following observations:

- The 5th inverter connected at the end of the line produces harmonics because of the high grid impedance. These harmonics propagate through the line causing the malfunction of other inverters. This can be seen by observing the last simulation with only 4 inverters connected to the grid where none of the inverters produces harmonics.
- The most critical hours are when the generation is higher and the consumption is lower. From the simulation at 17:00 it can be observed that the harmonic content at POC is lower than 7:00 due to the higher consumption.

In conclusion, this simulation environment based on Matlab software and the SimPowerSystems toolbox facilities evidences some of the phenomena reported as regards the harmonic contents of microgrids systems with PV distributed generation.

This environment can be exploited to evaluate new controller designs for grid-connected PV inverters which reduce the harmonic content of the grid. Furthermore, the environment flexibility allows the inclusion of other disturbances such as voltage drops, which can also help to the design of new inverter controllers improving the power quality of the grid.

ACKNOWLEDGMENT

This work has been partially supported by the Spanish Ministry of Science and Innovation through the grants RUE CSD2009-00046, Consolider-Ingenio 2010 Programme, DPI2006-15627-C03-01 and DPI2007-62582.

REFERENCES

- [1] J. H. R. Enslin and P. J. M. Heskes, "Harmonic interaction between a large number of distributed power inverters and the distribution network," in *Power Electronics Specialist Conference, 2003. PESC '03. 2003 IEEE 34th Annual*, vol. 4, 2003, pp. 1742–1747 vol.4. [Online]. Available: http://ieeexplore.ieee.org/xpls/abs_all.jsp?arnumber=1217719
- [2] J.-N. Paquin and D. Turcotte, "House model implementation for power quality studies," Tech. Rep., November 2007.
- [3] A. Green and K. Ellegård, "Consumer behaviour in swedish households: routines and habits in everyday life," Swedish Energy Agency.
- [4] N. Lu, Y. Xie, Z. Huang, F. Puyleart, and S. Yang, "Load component database of household appliances and small office equipment," in *Power and Energy Society General Meeting - Conversion and Delivery of Electrical Energy in the 21st Century, 2008 IEEE*, 2008, pp. 1–5. [Online]. Available: <http://dx.doi.org/10.1109/PES.2008.4596224>
- [5] G. R. Walker, "Evaluating mppt converter topologies using a matlab pv model," *Journal of Electrical & Electronics Engineering, Australia*, vol. 21, no. 1, pp. 49–55, 2001.